

# BRIGHT STARS IN THE GALACTIC GLOBULAR M5

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## Summary

We present a CCD investigation of the galactic globular M5 aimed to increase the statistical relevance of the available sample of evolving bright stars. Previous investigations, limited to the outer cluster region, have been extended toward the cluster center, more than doubling the number of observed luminous stars. On this basis, we discuss a statistically relevant sample, rich of 415 HB stars. The occurrence of a gap in the blue side of the HB is suggested. Comparison to the current evolutionary scenario discloses a good agreement concerning both the C-M diagram location and the relative abundance of stars in the advanced evolutionary phases, supporting our present knowledge of the evolution of low mass stars. Determination of the amount of the original helium content through the ratio  $R = N(\text{HB})/N(\text{RGB})$  gives  $Y = 0.22 \pm 0.02$ .

## 1. Introduction

As well known, current evolutionary theories concerning post main sequence evolution of globular cluster stars give relevant predictions not only about the CM location of the stars but also about their number distribution over the advanced evolutionary phases. The abundant literature on that matter already disclosed a general agreement between such a distribution and theory, supporting the current evolutionary scenario. However, this kind of investigation finds its natural limit in the statistical fluctuations affecting observational samples, so that any increase in the number of the observed stars implies an increase in the accuracy of the results, producing more stringent constraints to the theoretical frame.

Owing to the relatively large portion of sky covered by a galactic globular cluster, statistically significant investigations of cluster giants has been often produced on the basis

of photographic material, small field CCD techniques having mainly devoted to deep photometric investigations of selected portions of a cluster. According to such an occurrence, one finds that available investigations on the population of bright stars in globular clusters are typically limited to the outer regions of the clusters, neglecting the central regions where the crowding of the stellar images do not allow accurate photographic photometry.

However, CCD photometry joined to the modern procedures for image analysis allows a much deeper penetration in the crowded central fields, offering an ideal tool to complement the previous samples with rich populations of bright stars. This paper reports the result of a similar investigation, devoted to study luminous stars in the well known cluster M5 (=NGC 5904). The choice of the target and the production of the observational material were actually driven by a parallel investigation devoted to produce accurate curve of light for RR Lyrae variables in this cluster. However, since cluster luminous stars have been thoroughly studied by Buonanno et al.(1981) all over the region  $r > 120 \text{ arcsec}$ , we took advantage of our CCD coverage of the central region to improve the C-M diagram with new data, significantly enlarging the available sample of objects.

As we will discuss in the following sections, our CCD material allow to extend the investigation down to 20 arcsec from the cluster center, more than doubling the number of observed cluster giants. Next section will describe the observation and the reduction procedure. Sections 3 and 4 will deal with the discussion of the results, comparing observational data with evolutionary prescriptions for both H shell burning and He burning phases. We will find that both the number distribution of stars and their HR diagram location appear in agreement with theoretical prescriptions. On this basis, in the final

section we will present an updated evaluation of the cluster original He content.

## 2. The observations.

Observations have been performed at the 1.5 m Danish ESO telescope at La Silla during the night from 14 to 17 April 1989. The chip was RCA 512x331 , 0.5 arcsec/pixel sized. The cluster region was covered with four overlapping fields, as shown in fig. 1. Instrumental magnitudes were obtained on the basis of 4 exposures in each filter and for each field.

Exposure times were 40 sec for V filter and 90 sec for B. Flat fields and bias exposures were obtained at the beginning and at the end of each night to correct the CCD response to uniform sensitivity.

Data reduction was performed using ROMAFOT package for crowded photometry. All the magnitudes in the frames for a given field and with a given filter were normalized to the instrumental magnitudes of a reference frame, taking their average as the final value. These instrumental magnitudes were finally calibrated by comparison with 88 stars in common with the CCD investigation by Storm, Carney & Beck (1991) with  $V < 17$ . As a result we found

$$V = v + 27.13 \pm 0.02.$$

$$B - V = (1.097 \pm 0.009)(b - v) + 0.42 \pm 0.02.$$

with an internal error smaller than  $0.05\text{mag}$  in both colors for  $V \leq 18 \text{ mag}$ .

Completeness was tested by randomly adding to the original frames a set of stars of various magnitudes and colors. In this way we found that the sample of luminous stars ( $V \leq 17 \text{ mag}$ ) was fairly complete down to 20 arcsec from the cluster center. Thus in the

following we will refer only to the sample of 3736 stars located beyond the quoted limit. Data are directly available by E-mail request to the Authors or via Xmosaic at Teramo observatory WWW server. Fig. 2 shows the C-M diagrams of stars in selected anuli and the corresponding diagram for the whole sample of stars.

A quick look to the last figure shows three interesting features:

1) the well defined location of the AGB clump; 2) the evidence for the RG bump and, finally, 3) the probable but theoretically unsuspected occurrence of a gap in the HB distribution at  $B - V \simeq 0$  and  $V \simeq 15$ .

If this last point is real, thus M5 has to be added to the cluster (like M 15, see Buonanno et al 1981) showing this unexplained feature.

### 3. Theoretical scenarios

According to the current evolutionary scenario, the abundance of stars in a given advanced evolutionary phase is governed by the time spent by stars in that phase, resulting directly proportional to this time. On this basis, one finds in the literature stringent theoretical expectations concerning the distribution of stars along the Red Giant (RG) branch of a globular (see, e.g., Ferraro et al 1992 and references therein). According to the same philosophy, since the pioneering paper by Iben (1968) we know that the number ratio (R) of HB stars to RGs at luminosities larger than the HB luminosity level gives information about the amount of original Helium in cluster stars. We can add that detailed computations of post HB evolution, as given in Castellani, Chieffi & Pulone 1991 (herein after CCP), already produced theoretical expectations also about the number ratio between HB and Asymptotic Giant Branch (AGB) stars . Thus the comparison of all these expectations

with a rich sample of luminous stars will be of great interest.

However, before approaching such a comparison it is worth to recall in some detail the theoretical frame. One may notice that the observational parameters one is dealing with do have an internal connection. As a matter of fact, the evaluation of the amount of original He through the R-method implies the following three assumptions:

- i) Theoretical estimates of the evolutionary times along the RG branch are correct,
- ii) Similar estimates for the evolutionary times in the HB phase are also correct.
- iii) The luminosity of HBs do follow the canonical dependence on the amount of original He.

As for the first point, RG lifetimes appear a well established theoretical result (see, e.g., the discussion in Castellani & Norci 1989, hereinafter CN) which only needs comparison with observations. The next two points require more attention.

Current canonical theories concerning HB evolution and ,thus, HB lifetimes assume the efficiency of semiconvection with a negligible efficiency of the so called "breathing pulses". However, it has been suggested that semiconvection could be overcome by the efficiency of a strong overshooting (Bressan, Bertelli & Chiosi 1989). In general, one expects that any variation in the estimates of convective mixing in the stellar core could deeply affect HB lifetimes. Comparison with RG lifetimes (Caputo et al 1989) already supported the reliability of the canonical semiconvective scenario. The availability of canonical prescriptions about post HB evolutionary phases allow now a further relevant test on the matter. A more efficient mixing increases the mass of the He depleted core at the end of HB evolution and a larger HB lifetime is consequently obtained. Moreover, the luminosity of the bottom level

of the AGB is also increased and the number ratio between AGB and HB stars decreases, with respect to the value fixed by canonical evaluation at  $N_{AGB}/N_{HB} = 0.12 \pm 0.01$  (CCP).

The actual luminosity of HBs has been finally seriously debated in the current literature. Evidences for the so called Sandage's effect (see Sandage 1993 and reference therein) and/or the results of Baade Wesselink analyses of RR Lyrae stars raised the suggestion for a discrepancy between canonical predictions and the actual luminosity of these HB stars. Even if, in our feeling, there is an increasing evidence against a similar occurrence (see, e.g., Castellani, Degl'Innocenti & Luridiana 1993: CDL) one has to bear in mind all this scenario to approach a correct discussion of the data we will deal with.

## **The Red Giant Branch**

To follow the various arguments in the quoted order, let us discuss first RG branch stars. If  $N$  represents the number of giants in a given interval of luminosity, thus theoretical predictions can be put in the form

$$\log N = A - B \log L + C(L_b)$$

where  $A$  is a constant of normalization to the total number of observed stars whereas the slope  $B$  is predicted by the theory.  $C(L_b)$  is an additional term representing the "bump" superimposed to the general distribution at the luminosity  $L_b$  where the H burning shell encounters the H discontinuity in the stellar interior. In principle, comparison of the slopes does not require a precise determination of the absolute magnitudes  $M_v$  and, in turn, of the cluster distance modulus  $DM$ . However, to estimate the luminosity of the bump one needs such an evaluation. To this purposes, let us adopt the distance modulus derived assuming for the HB the canonical luminosity as derived for the suitable choice about the chemical

composition  $Z=0.001$ ,  $Y=0.23$ . On this basis one can estimate for M5  $DM = 14.4 \pm 0.1$  (CCP).

The large sample of giants we are dealing with allows the analysis of the distribution of the giants binned in 0.1 *mag* intervals, which appears the most appropriate procedure to compare observation with theoretical constraints, as more deeply discussed in CN. Fig.3 compares the observed distribution with the corresponding theoretical prediction as obtained from a synthetic RG branch populated with the same number of stars as observed. Inspection of this figure reveals a good correspondence between observed and predicted slope of the distribution, an occurrence which supports theoretical evaluations concerning the core mass versus luminosity relation for RG structures and, as a consequence, provides a strong support to the general reliability of theoretical evolutionary times for low mass red giants.

As a further relevant feature, one finds that the RG "bump" is clearly detected and located in the interval  $V\ 14.9 - 15.0$  m, about 0.4 magnitudes fainter than what expected by theoretical side. This is a well known occurrence common to other galactic globulars, widely discussed by Fusi Pecci et al (1990). On evolutionary grounds, this can be taken as an evidence that surface convection sinks down a bit more than expected in canonical computations, with negligible outcome on the general evolutionary scenario. Here let us only remind that such a discrepancy can be, at least in part, connected to a not solar ratio of heavy elements in Population II stars, with enhancement of the alpha-elements.( e.g. Salaris et al 1993)

However, comparison with theoretical prescriptions, as given in CN, discloses a series



of interesting concordances. As a first point, one finds that the distribution in luminosity agrees with theoretical predictions, for which the bump should not exceed the typical width of about 0.1 magnitudes. Even more interesting, one finds that the amplitude of the bump closely follows the predictions given in CN. According to the analysis given in that paper, for the assumed cluster chemical composition ( $Y=0.23$ ,  $Z=0.001$ ) and for a cluster age of the order of 15 billion years, one expects a "contrast" of the bump above the continuous sloping distribution as given by  $D \log N \simeq 0.5$ , as observed.

In this respect, we can conclude that the distribution of stars along the red giant branch of M5 gives a satisfactory support to current evaluations about red giant evolution, which can be regarded among the best established evolutionary phases of low mass stars. The discrepancy in the bump luminosity remains an open question which deserves further investigation. Here we wish only to notice that the observed bump, though fainter than expected, remains above the luminosity of the horizontal branch, still contributing to the number of giants to be taken into account in the evaluation of the parameter  $R$ . Accordingly, the fainter magnitude should have a negligible influence on the total number of giants, and we will hold on the  $R$  calibration given by Buzzoni et al (1983) on the basis of canonical computations.

#### **4. The He burning phases.**

As a first evolutionary test, let us approach the problem of the HR diagram location of He burning stars by comparing in Fig.4 the observed C-M diagram for luminous stars with the corresponding theoretical predictions as taken from CCP. Buonanno et al. (1981) discussed possible evidences for a disagreement between theory and observations, as given

by the suggested overluminosity of the bluest portion of the observed HB branch. However, fig.4 shows that theoretical evolutionary tracks, when translated into the color magnitude diagram by adopting color temperature relations and bolometric corrections from Kurucz (1979), fairly fit the observed distribution all along the horizontal branch, thus overcoming the quoted problem.

As a very important point, let us notice that fig. 4 shows a close agreement not only for the HB phases but also, and in particular, for the luminosity of the clump of AGB stars marking the initial phases of double shell He burning phases. As already discussed, this is an evolutionary parameter which critically depends on the extension of central convective mixing in the previous central He burning structures. The observed agreement gives thus a relevant support to the adopted treatment of semiconvection in He burning stars.

As discussed in a previous section, the number ratio between HB and AGB stars is another indicator of the efficiency of convective or semiconvective mixing during the major phase of central He burning. Canonical evaluations performed under the assumptions  $Y = 0.23$  (CCP) give the prediction  $N_{AGB}/N_{HB} = 0.12 \pm 0.01$ , independently of the assumptions about the cluster metallicity or about the color distribution of HB stars. To discuss these and other features of HB stars in M5 we report in Table 1 selected quantities derived from our observational results together with similar results as presented by Buonanno et al. (1981) for stars in the external region of the cluster. As for our results, table 1 gives separately data for  $r \leq 120 \text{ arcsec}$ , to be added to Buonnanno's sample to produce the "complete" sample, and data for  $r \geq 120 \text{ arcsec}$  wich extend our sample to outer regions already covered by Buonanno et al.

It appears that the present investigation is more than doubling the number of He burning stars found in the cluster, with a significant improvement on the statistical relevance of the sample. As for the number ratio of AGB to HB stars, our sample gives  $N_{AGB}/N_{HB} = 0.119 \pm 0.029$ , a figure which closely overlaps theoretical predictions. However, if one complements the data by Buonanno et al. with our data for  $r \leq 120 \text{ arcsec}$ , one finds a slightly different result, namely  $N_{AGB}/N_{HB} = 0.147 \pm 0.026$ . As a matter of fact, data in table 1 disclose that the samples we are now dealing with, have a similar number of AGB stars, our sample being richer of HB stars than Buonanno et al. This is a rather curious occurrence, since our samples for  $r \leq 120 \text{ arcsec}$  and for  $r \geq 120$  have very similar values for this ratio. Thus it appears that the overabundance of AGB stars in Buonanno's sample is just coming from the region of cluster outside our investigation.

However, one finds that the number ratio between AGB and HB stars in the complete sample still remains in agreement with theoretical predictions within 1 sigma. Since any discussion within the quoted error is not really meaningful, one can only conclude that theory and observation appear in agreement also for such a relevant evolutionary parameter. One may conclude that evolving stars in the galactic globular M5 appears to be distributed in the HR diagram according to all the available theoretical prescriptions, an agreement which allow us to be confident in our theoretical understanding the evolution of low mass stars in galactic globulars.

On this basis, one becomes also more and more confident in the theoretical scenario supporting the calibration given by Buzzoni et al (1983) of the parameter  $R$  as a function of the original He content in cluster stars. According to the normal procedure, let us define

R as the number ratio between HB stars and RG stars more luminous than the mean bolometric luminosity of the HB at the RR Lyrae gap. Adopting  $V = 15.10 \text{ mag}$  as the appropriate HB luminosity level and  $V = 15.25 \text{ mag}$  as the corresponding  $V$  magnitudes along the RG branch, from the ratio of the corresponding counts as given in Table 1 one derives

$$R = 1.28 \pm 0.13$$

where the error ( $1 \sigma$ ) account for the expected statistical fluctuations of the counts. From our data, one finds that a variation of  $\pm 0.1 \text{ mag}$  in the lower luminosity boundary of the RG sample gives a variation of  $\pm 0.03$  in R. Thus the statistics is still the main source of indetermination in this analysis. By adopting the Buzzoni et al (1983) calibration, one finally finds

$$Y = 0.22 \pm 0.02$$

which we present as an updated evaluation of the original amount of He in stars membering the galactic globular M5.

## 5. Conclusions

In this paper we presented a new CCD investigation of luminous stars in the galactic globular cluster M5, extending to the cluster central regions a previous investigation given by Buonanno et al. (1981) on post main sequence evolutionary phases. On this basis, we secured a statistically relevant sample, rich of 415 HB stars, to be compared to theoretical constraints concerning the number of stars populating RG, HB and AGB branches.

The comparison revealed a general agreement between theoretical prediction and the observed numbers of stars, supporting the results of current theoretical computations con-

cerning the evolution of low mass stars both during the H and the He burning phases. A further support to these computations has been also found in the good theoretical fitting of the HB CM diagram location and, in particular, in the correct prediction of the luminosity of the AGB clump.

According to such an agreement, we present a new evaluation of the original He content of cluster stars, as given by the value  $Y = 0.22 \pm 0.02$  which reconciles previous evaluation presented by Buonanno et al. ( $Y=0.17$ ) with the general belief of an amount of cosmological He of the order of  $Y=0.23$ .

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## Figure captions

Fig. 1: The sky location covered by our four CCD frames in the field of the cluster M5.

The circle ( $r=120$  arcsec) shows the inner boundary of the region photographically explored by Buonanno et al. (1981)

Fig.2: The C-M diagram for stars in selected regions of the cluster, as labeled, and for the total sample of measured stars. Arrows indicate the three features discussed in the text.

Fig.3: The observed distribution with luminosity of the number of red giants binned in 0.1 mag intervals (full line). Dashed line shows the result of a theoretical simulation as obtained populating a red giant branch with the same number of stars as observed.

Fig.4: The observed C-M diagram for our sample of luminous stars in M5 compared with theoretical evolutionary tracks from CCP for  $Z=0.001$ ,  $Y=0.23$

Table 1: Number of cluster giants in the various evolutionary phases and for selected cluster regions, as labelled.

N(HB)	N(RGB)	N(AGB).	
251	184	30	a) This paper, $20 < r < 120arcsec$ .
164	140	31	b) Buonanno et al., $r > 120arcsec$ .
415	324	61	c) Complete sample, a + b.
77	84	12	d) This paper, $r > 120arcsec$